VICTORIA UNIVERSITY OF WELLINGTON
TE HERENGA WAKA
NEW ZEALAND

XMUT204 Electronic Design

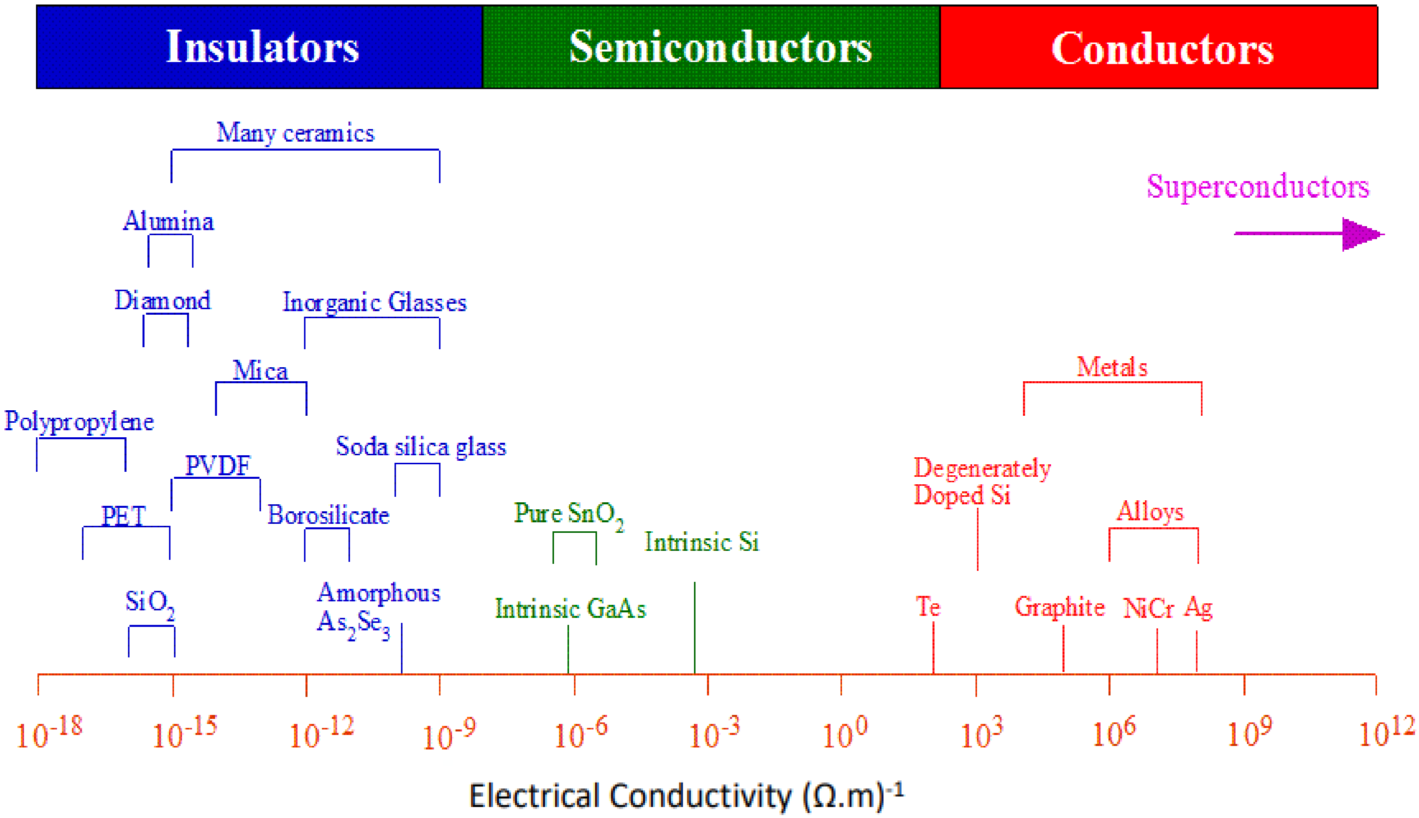
Lecture 1a - Introduction to Semiconductors

Overview

1. Conductivity and resistivity of materials.
2. Characteristics of semiconductor.
3. Lattice structure.
4. Doping of semiconductor materials.

1. Conductivity and Resistivity of Materials

- The conductivities of various materials i.e. insulators, semiconductors and conductors.



1. Conductivity and Resistivity of Materials

- Conductivity coefficient of the materials is calculated from:

$$\sigma = ne\mu$$

Where:

n = number of conduction electrons/cm^3.

e = electron charge (1.6×10^{-19}).

μ = mobility of electrons.

- Unit of conductivity coefficient of materials is Siemens per meter (S/m).

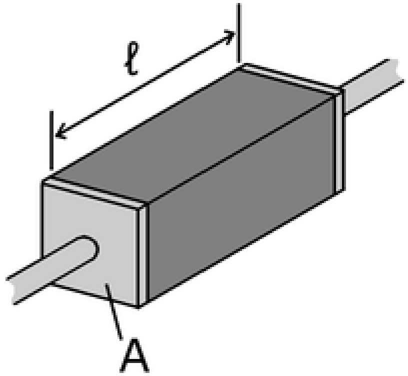
1. Conductivity and Resistivity of Materials

- Resistivity coefficient of the materials is the inverse of conductivity coefficient:

$$\rho = 1/\sigma$$

- Resistance of materials (R) is calculated from:

$$R = \frac{\rho l}{A}$$



Where:

- ρ is resistivity of the material.
- l is the length of the material.
- A is the cross-sectional area of the material.

- Units of resistivity of materials is Ohm meter (Ω-m).

1. Conductivity and Resistivity of Materials

Factors that affect conductivity (and also resistivity) coefficient of materials.

- **Cross-Sectional Area:** If the cross-section of a material is large, it can allow more current to pass through it.
- **Length of the Conductor:** A short conductor allows current to flow at a higher rate than a long conductor.
- **Temperature:** Increasing temperature makes particles vibrate or move more. More of this movement (higher temperature) decreases conductivity because the molecules are more likely to get in the way of current flow. At extremely low temperatures, some materials are superconductors.

1. Conductivity and Resistivity of Materials

- Resistivity and conductivity coefficients of various materials.

Material	Resistivity	Conductivity
C (Graphite)	1.0×10^{-8}	1.0×10^{8}
Ag	1.6×10^{-8}	6.3×10^{7}
Cu	1.7×10^{-8}	5.9×10^{7}
Au	2.4×10^{-8}	4.2×10^{7}
Al	2.7×10^{-8}	3.7×10^{7}
Fe	9.7×10^{-8}	1.0×10^{7}
C (Amorphous)	5.0×10^{-4}	2.0×10^{3}
Si (Pure)	6.4×10^{2}	1.6×10^{3}
Glass (Silica)	1.0×10^{11}	1.0×10^{-11}
C (Diamond)	1.0×10^{12}	1.0×10^{-12}
Teflon	1.0×10^{24}	1.0×10^{-24}

Example for Tutorial 1:

1. What is the resistance of an Aluminium wire that has diameter of 2 mm and length of 10 m?

   Note that an Aluminium has resistivity coefficient, $\rho = 2.65 \times 10^{-8}\ \Omega m$.

   [2.5 marks]

2. Calculate the electrical conductivity of the material of a conductor of length 3 m, area of cross section $0.02\ mm^2$ having a resistance of $20\ \Omega$. [2.5 marks]

1. Resistance of the material, R is calculated from:

$$R = \frac{\rho L}{A} = \frac{L}{\sigma A}$$

Cross sectional area of the round wire (A) with a radius of r is calculated from:

$$A = \pi(r)^2$$

Putting in the values to the equation:

$$R = \frac{(2.65 \times 10^{-8})(10)}{\pi(1 \times 10^{-3})^2} = 8.44 \times 10^{-2}\ \Omega/\text{m}$$

2. For the given conductor, its resistance is calculated from:

$$R = \frac{\rho l}{A}$$

Rearrange the equation above, the resistivity of the conductor is:

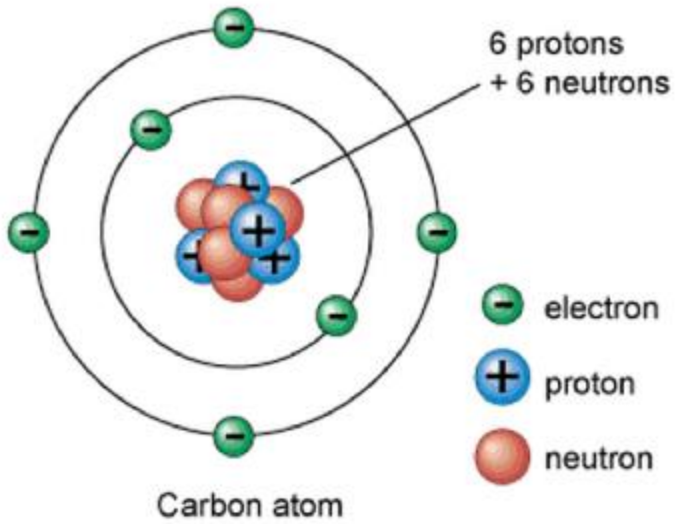
$$\rho = \frac{RA}{l} = \frac{(20)(2 \times 10^{-5})}{3} = 13.33 \times 10^{-5}\ \Omega\text{m}$$

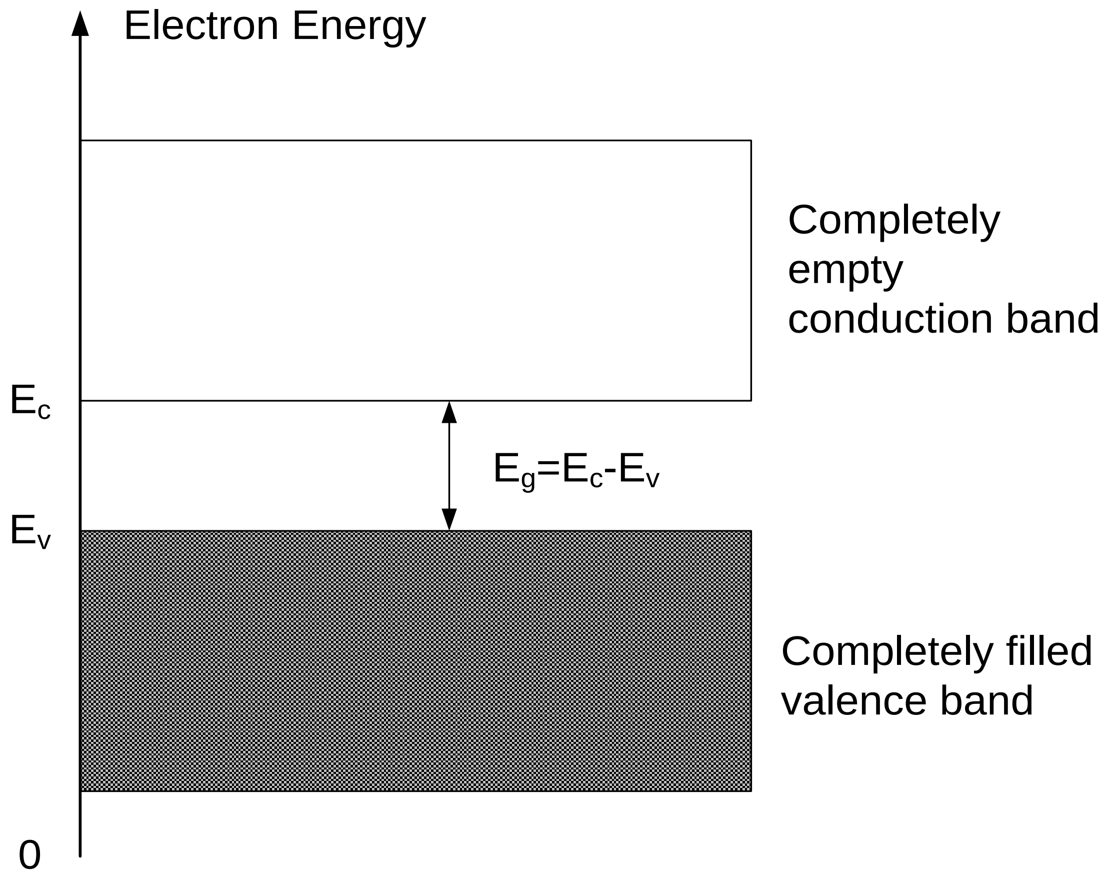
Since resistivity of the conductor ρ is $13.33 \times 10^{-5}\ \Omega\text{m}$, the electrical conductivity of the conductor is:

$$\sigma = \frac{1}{\rho} = \frac{1}{13.33 \times 10^{-5}} = 0.075\ \text{S/m}$$

2. Characteristics of Semiconductor

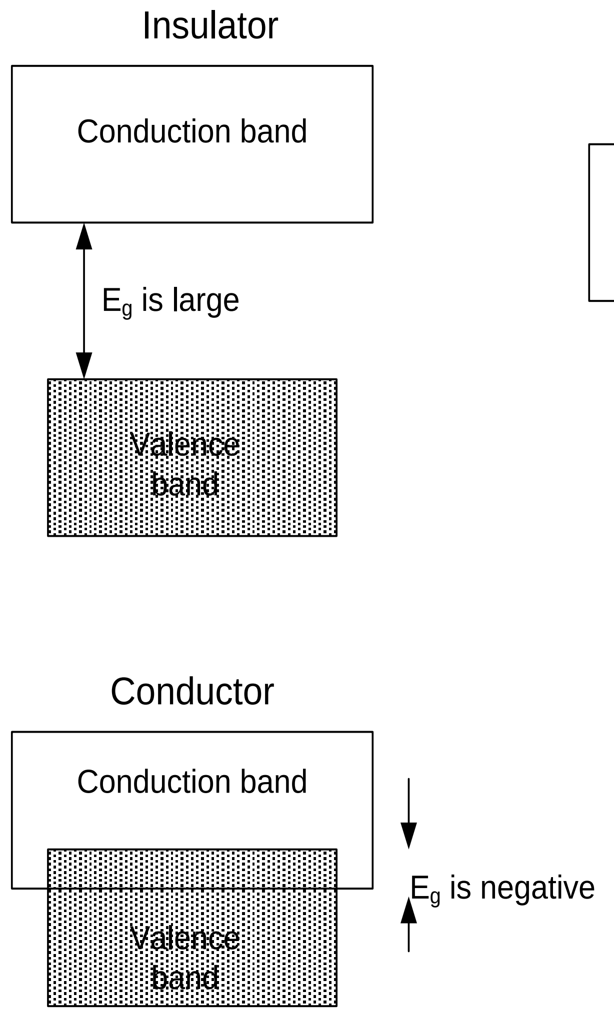
- The electron energy band structure of a solid material.





2. Characteristics of Semiconductor

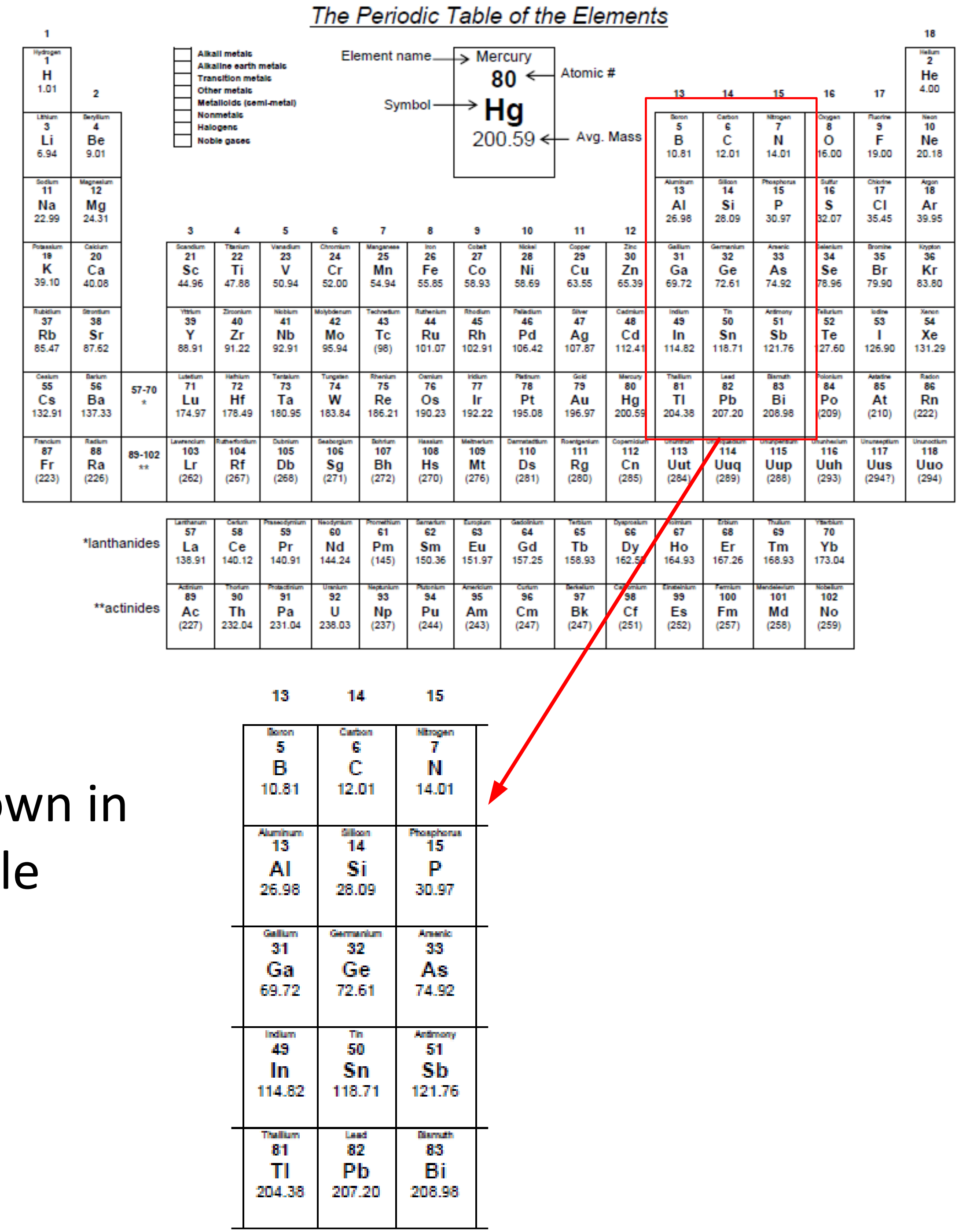
- Energy band structure of various materials.



- Notice the differences in the gap band of conductors, semiconductors and insulators materials.

2. Characteristics of Semiconductor

- Semiconductor materials as shown in the periodic table



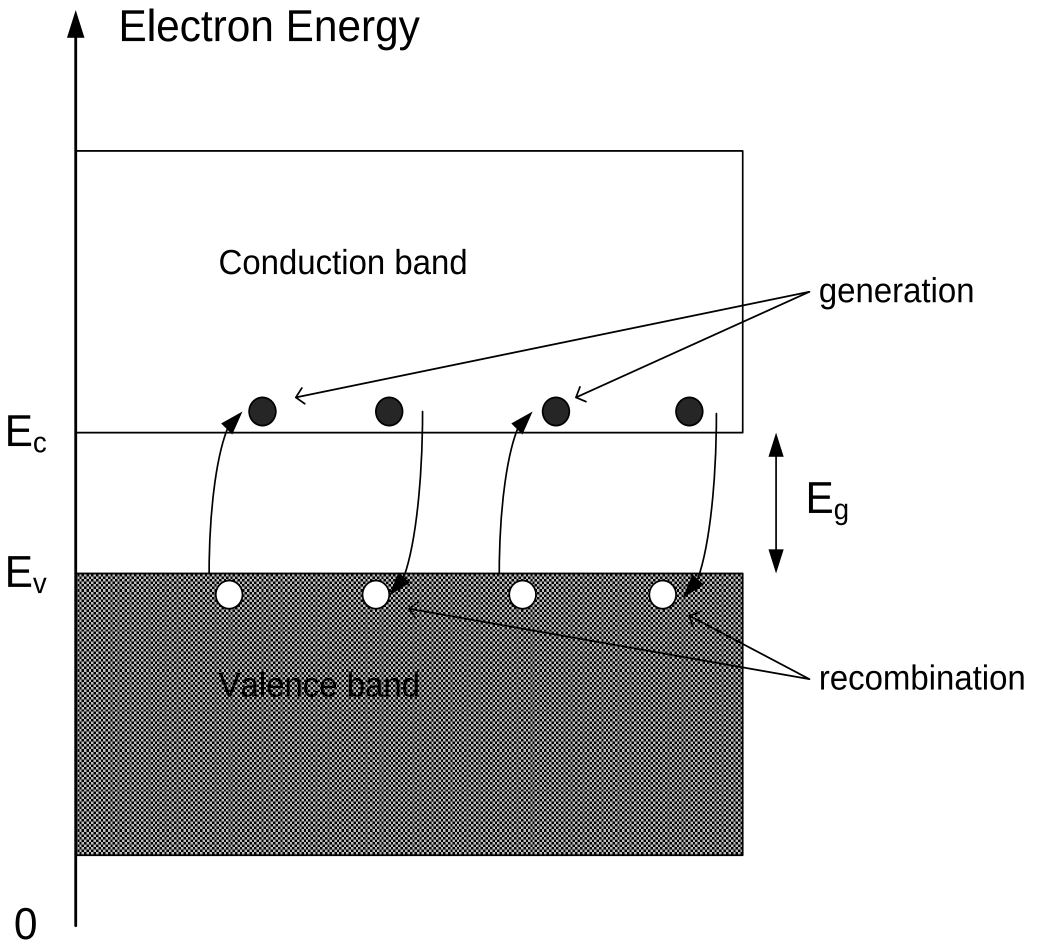
2. Characteristics of Semiconductor

- Chemical characteristics of various semiconductor materials of the first five elements down Group 14 of the periodic table.

Element	Atomic Number	E_g (eV)	Classification	Bonding
C (Diamond)	6	5.5	Insulator	Covalent
Si	14	1.1	Semiconductor	Covalent
Ge	32	0.7	Semiconductor	Covalent
Sn	50	0 (-)	Conductor	Metallic
Pb	82	0 (-)	Conductor	Metallic

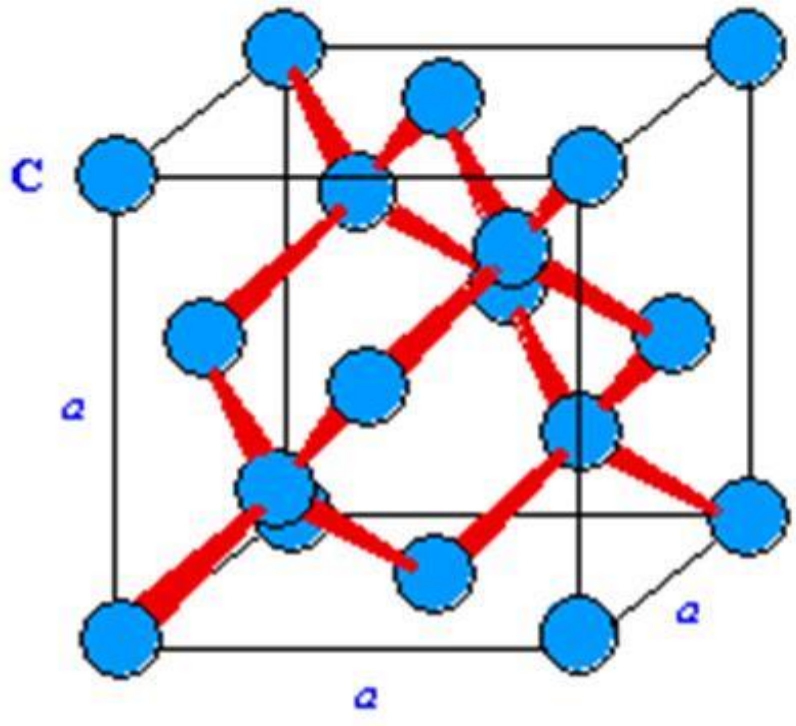
2. Characteristics of Semiconductor

- Electron – hole generation happen due to excitation.
- Nearby electron – hole pair can perform recombination.
- Electron – hole generation and recombination can happen at the same time.

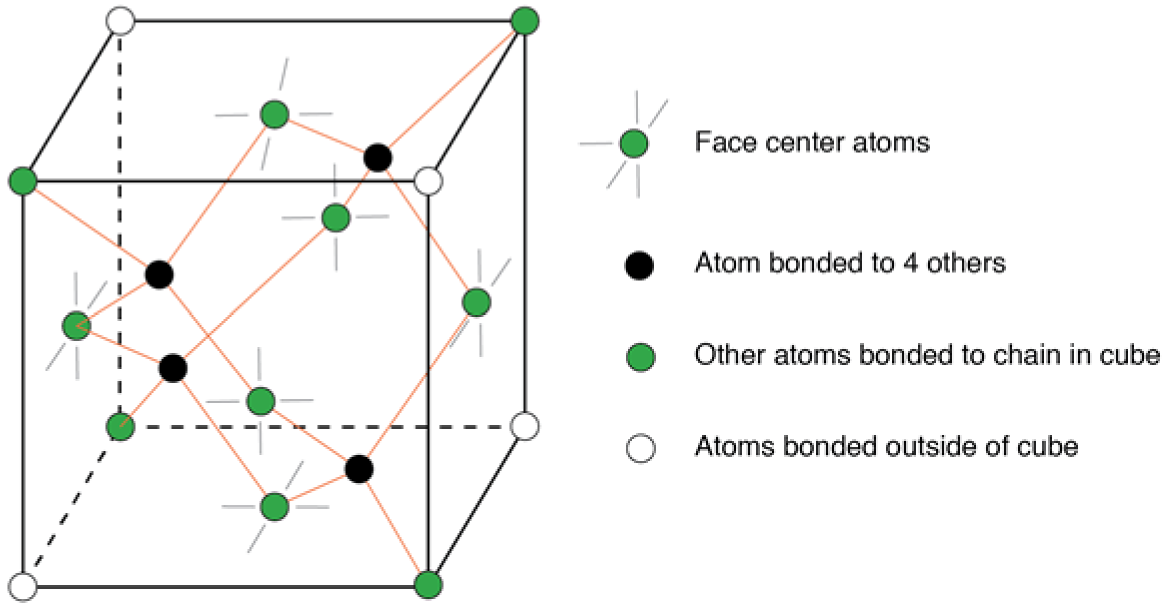


3. Lattice Structure of Semiconductor Materials

- A single unit cell of the Silicon crystal structure (side length, a = 0.54 nm)



3. Lattice Structure of Semiconductor Materials

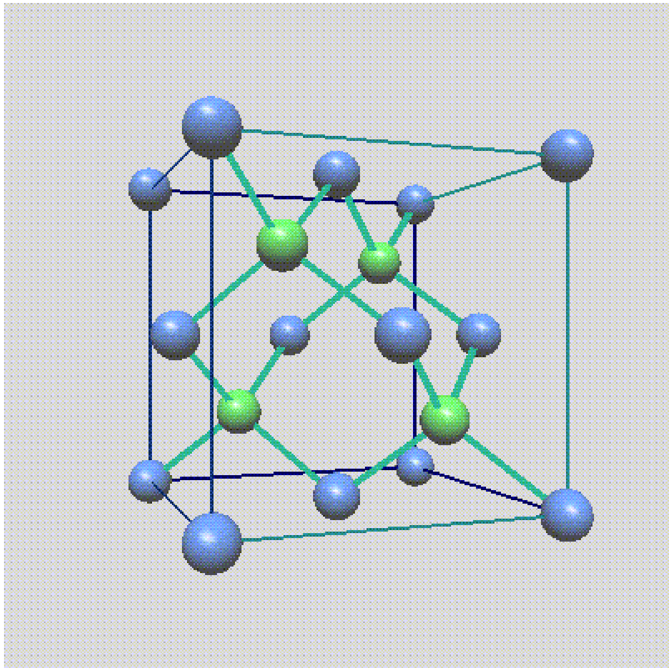


- To calculate number of atoms in a cell of the Silicon crystal structure:
  - 1/8 of 8 atoms on the corners = 1 atom.
  - 1/2 of 6 atoms on the faces (sides) = 3 atoms.
  - 1 of 4 atoms inside the crystal = 4 atoms.

Example for Tutorial 2:

1. Determine the number of atoms in a unit cell of GaAs crystal as shown below. Calculate the number of Ga and As atoms in the lattice for 1 cm^3 of material (note that length of each side of the unit cell is 1.2 nm).

[10 marks]



- To calculate number of atoms in a given Silicon materials:
  - No of atoms in a cell = corner + side + center = 4 + 3 + 1.
  - No of cells in 1 cm^3 of Silicon crystal materials:

$$\text{No of cell} = \frac{1}{(a)^3}$$

  - No of atoms in the 1 cm^3 Silicon materials:

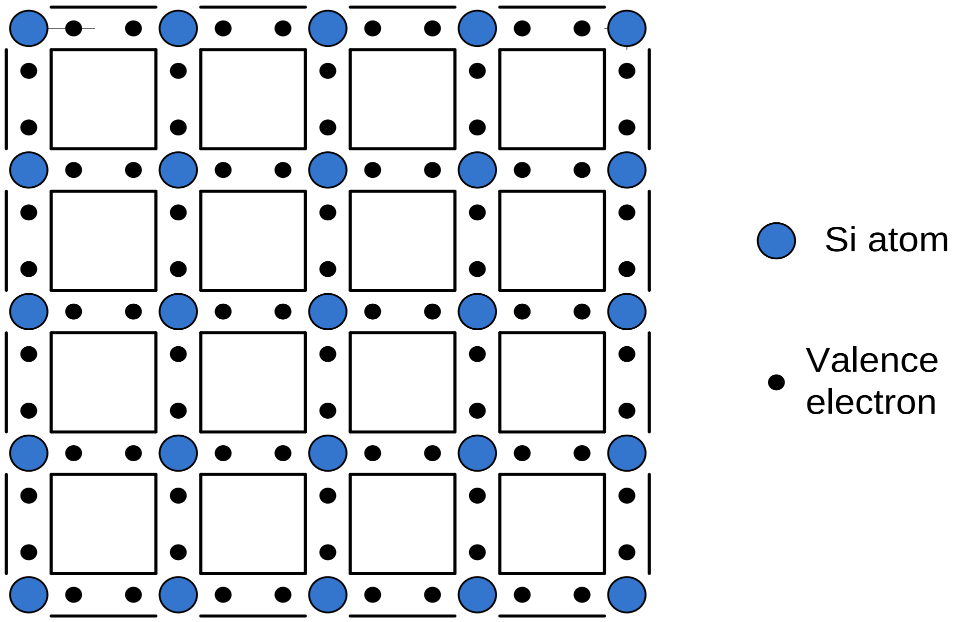
$$\text{No of atoms} = (\text{no of atoms in a cell})(\text{no of cell})$$

Or

$$\text{No of atoms} = (4 + 3 + 1)\frac{1}{(0.54 \times 10^{-9})^3}$$

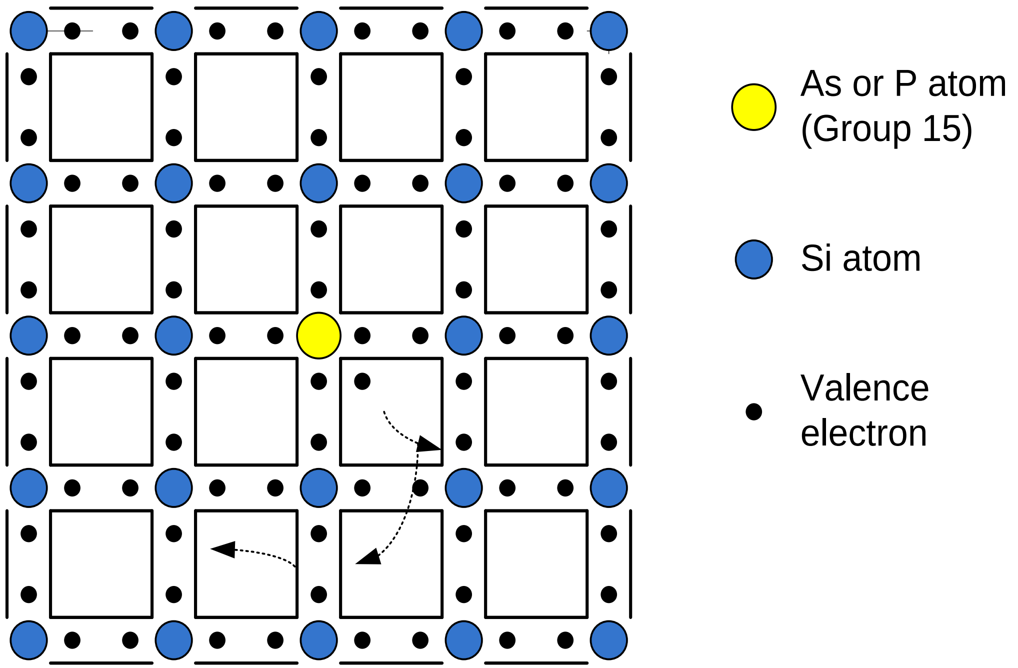
4. Doping of Semiconductor Materials

- Doping means adding other material (dopant) into a pure semiconductor material.
- Its purpose is to change and enhance the property of the semiconductor material.
- A 2D representation of the (intrinsic) Si structure.



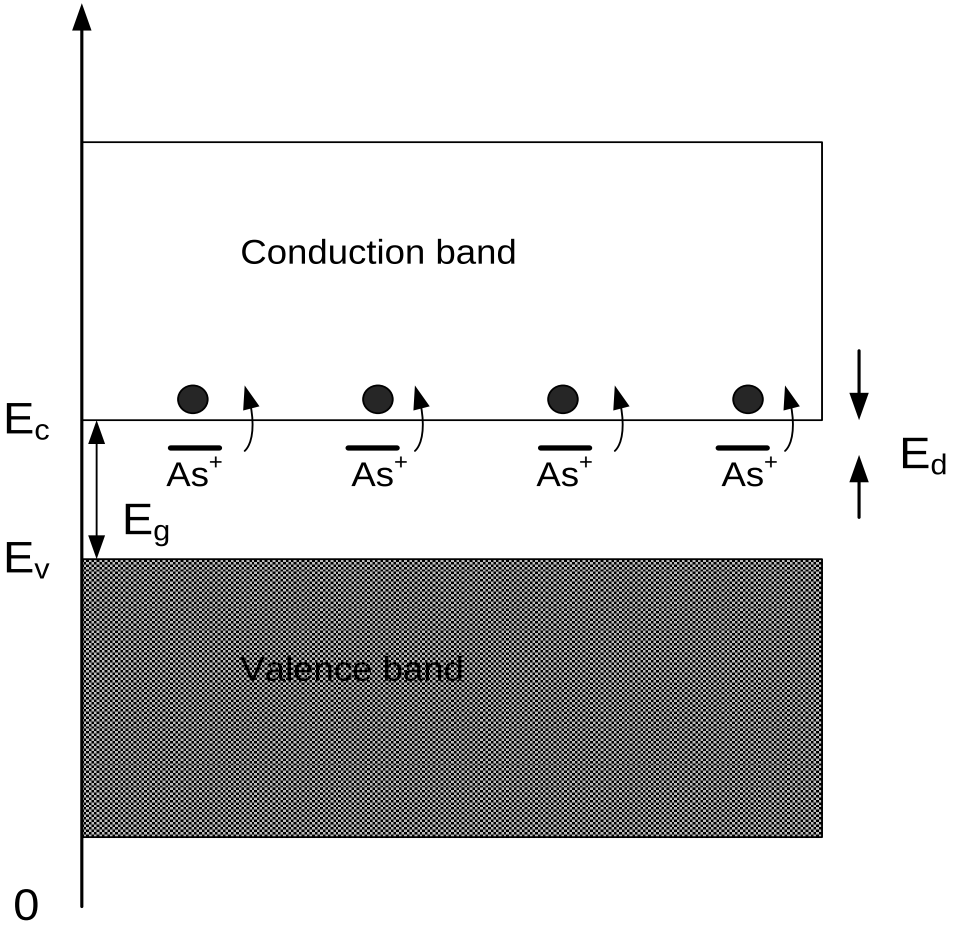
4. Doping of Semiconductor Materials

- A 2D representation of the Si lattice containing n –type dopant (As or P) e.g. Group 15 atoms.
- Doping atoms introduce extra electrons in the structure.



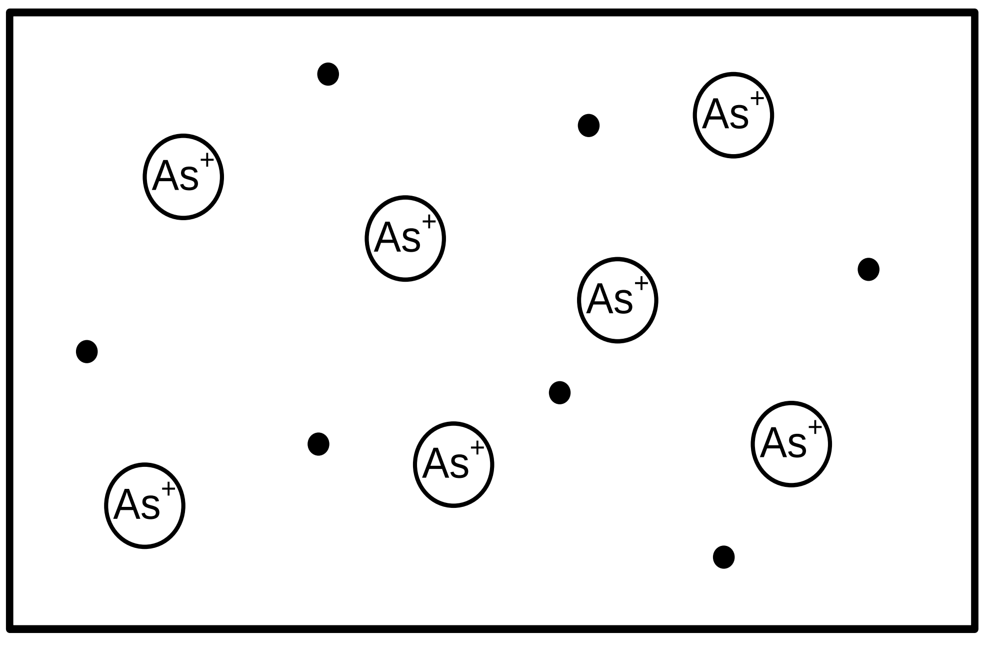
4. Doping of Semiconductor Materials

- The band structure of a n-type semiconductor.
- Electrons are present in the conduction band.



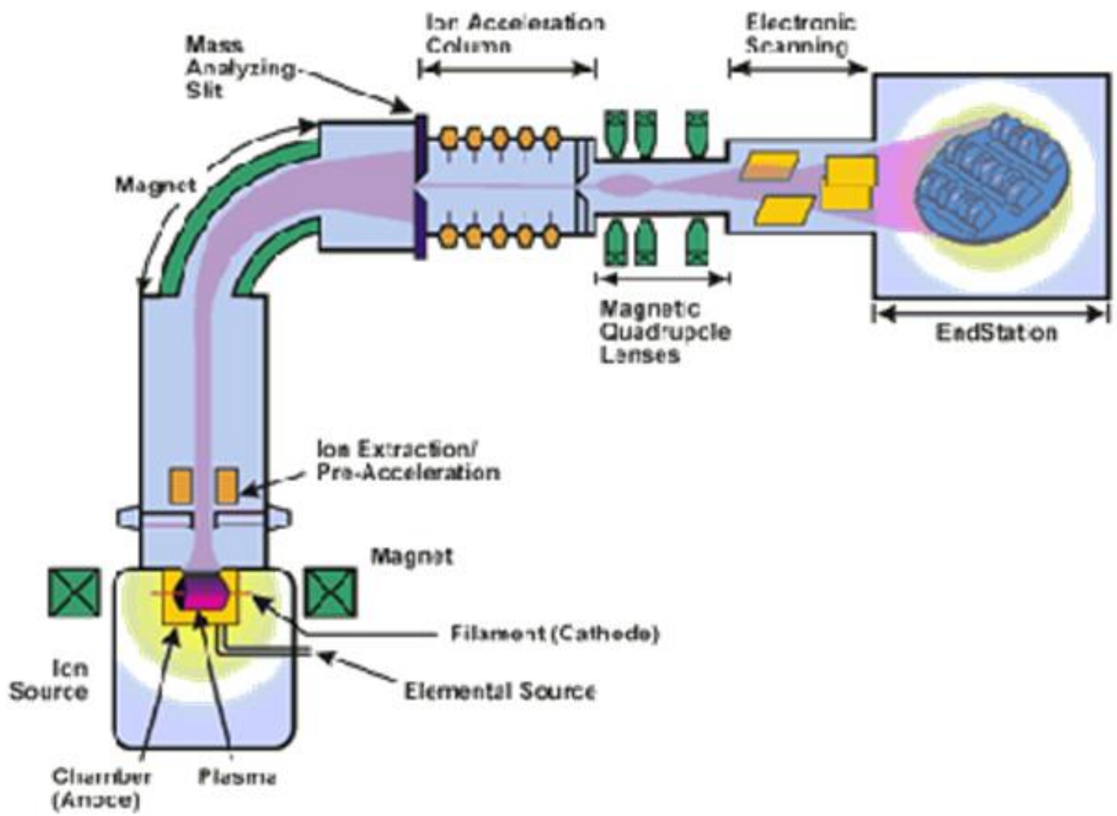
4. Doping of Semiconductor Materials

- Representation of a silicon lattice containing a n-type dopant.
- Note the extra electrons floating around.



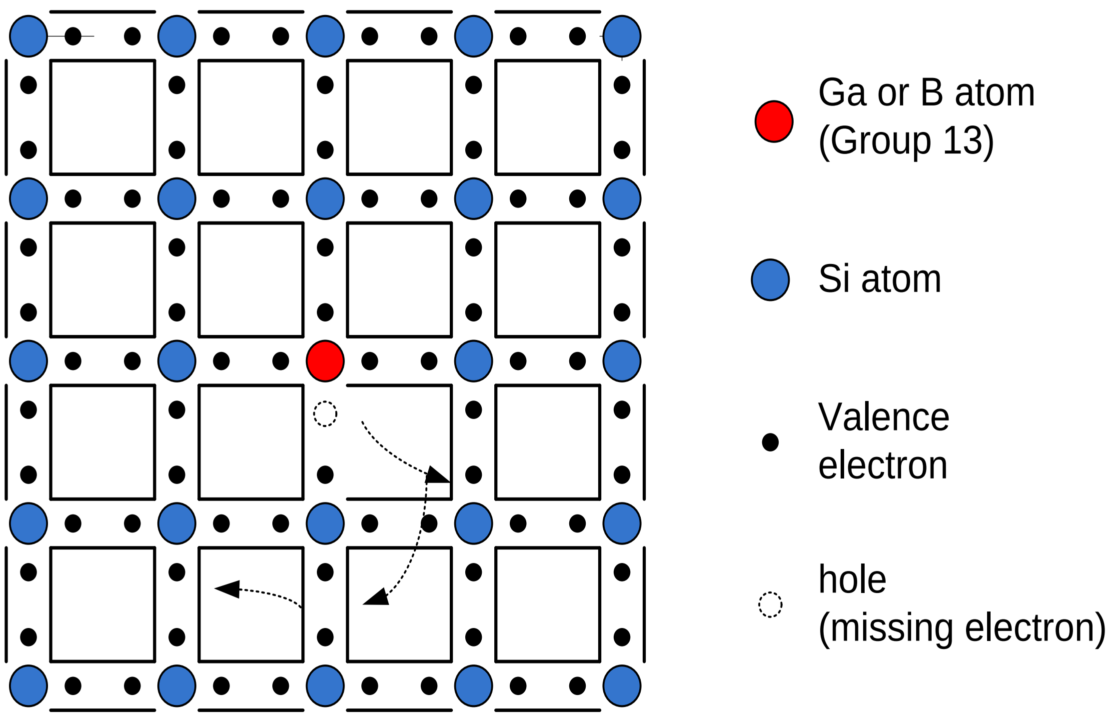
4. Doping of Semiconductor Materials

- In practice, doping atoms is to accelerate and deposit impurities (e.g. other atoms or dopants) into the semiconductor material structure.



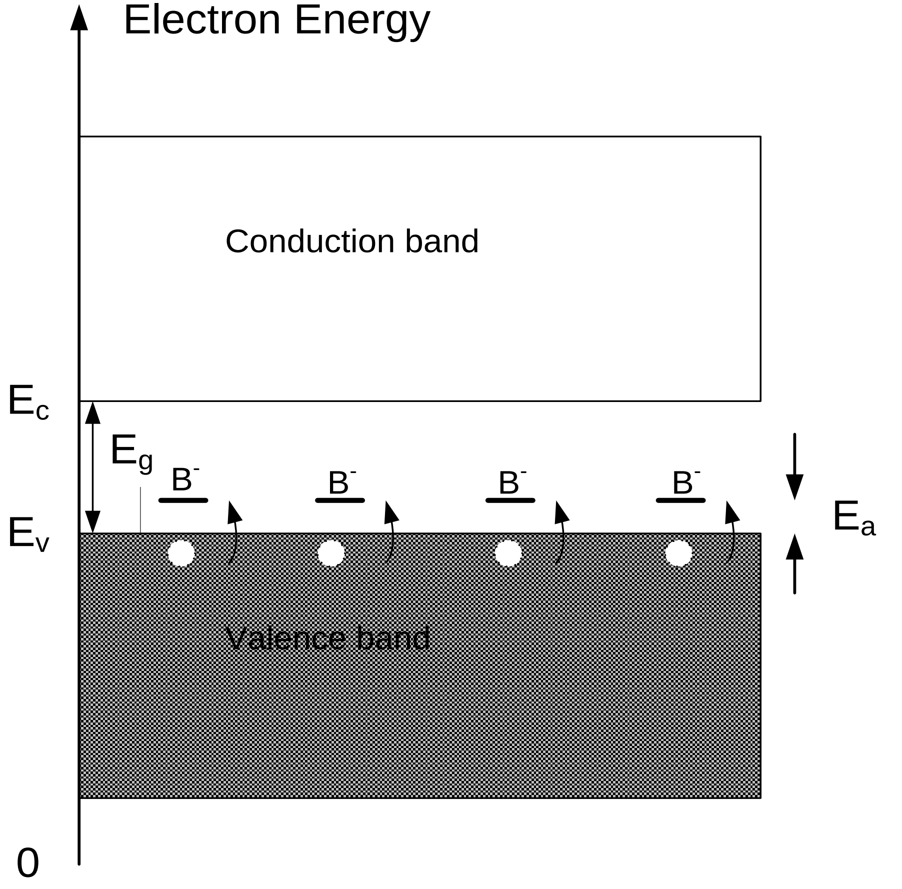
4. Doping of Semiconductor Materials

- The effect of adding an element from Group 13 into the Si lattice i.e. Ga or B.
- Doping atoms introduce holes in the structure.



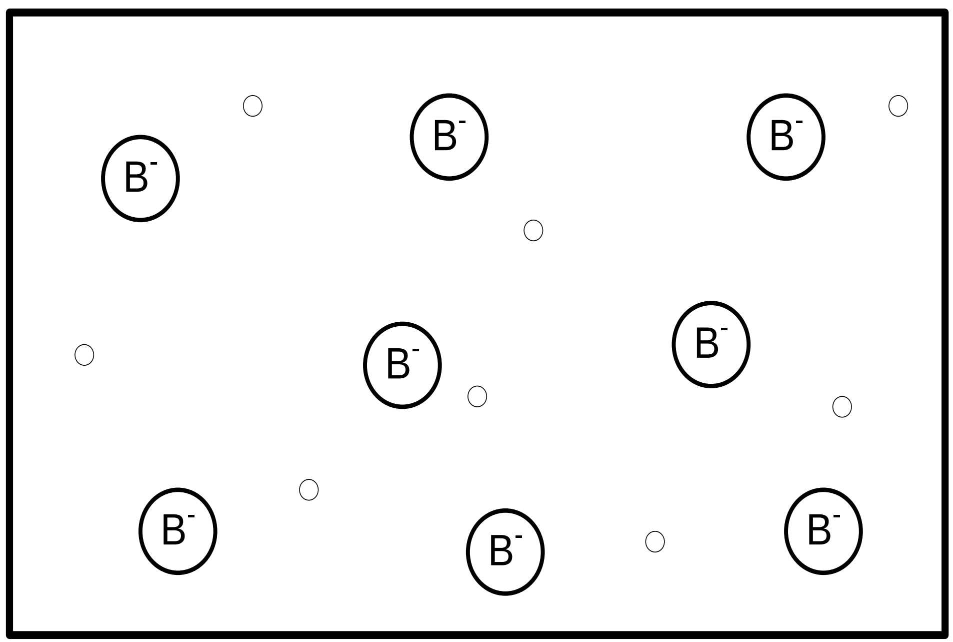
4. Doping of Semiconductor Materials

- Energy band diagram of p-doped silicon.
- Holes are present in the valence band.



4. Doping of Semiconductor Materials

- Representation of a silicon lattice containing a p-type dopant.
- Note the present of holes in the structure.



4. Doping of Semiconductor Materials

- To accommodate the influence of both types of carriers on the conductivity, it is calculated from:

$$\sigma = ne\mu_e + pe\mu_h$$

Where:

- n is the electron density and μ_e is the electron mobility.
- e is the electrical charge (1.6 x 10^{-19} C).
- p is the hole density and μ_h is the hole mobility.

- Both carriers contribute to the conductivity and current that flow e.g. the electron and hole current do not cancel each other out, but they add to the total current observed.

Example for Tutorial 3:

1. Calculate the conductivity of a Silicon material if it has intrinsic carrier concentration 1.5×10^{16} per m^3 and the mobilities of the electron and hole are 0.15 m^2/Vs and 0.05 m^2/Vs respectively.

[2.5 marks]

Conductivity of the material, σ is calculated from:

$$\sigma = ne\mu$$

Assuming the mobility of the particles in the materials are due to electrons and holes, then the overall mobility is:

$$\mu = \mu_e + \mu_h$$

Putting in the values into the equation:

$$\sigma = (1.5\times\ 10^{16})(1.602\times 10^{-19})(0.15+0.05)$$

$$= 4.81\times 10^{-4}\ \mathrm{S/m}$$